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Smart phones: Platform Enabling Modular, Chemical, Biological, and Explosives Sensing

by Amethist S. Finch, Matthew Coppock, Justin R. Bickford, Marvin A. Conn, Thomas J. Proctor, and Dimitra N. Stratis-Cullum

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NOTICES

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14. ABSTRACT

Reliable, robust, and portable technologies are needed for the rapid identification and detection of chemical, biological, and explosive (CBE) materials. A key to addressing the persistent threat to U.S. troops in the current war on terror is the rapid detection and identification of the precursor materials used in development of improvised explosive devices, homemade explosives, and bio-warfare agents. However, a universal methodology for detection and prevention of CBE materials in the use of these devices has proven difficult. Herein, we discuss our efforts towards the development of a modular, robust, inexpensive, pervasive, archival, and compact platform (android based smart phone) enabling the rapid detection of these materials.

15. SUBJECT TERMS

Smartphone, ubiquitous sensing, explosives sensing, chemical sensing, biological sensing

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Smart phones: platform enabling modular, chemical, biological, and explosives sensing

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ABSTRACT

Reliable, robust, and portable technologies are needed for the rapid identification and detection of chemical, biological, and explosive (CBE) materials. A key to addressing the persistent threat to U.S. troops in the current war on terror is the rapid detection and identification of the precursor materials used in development of improvised explosive devices, homemade explosives, and bio-warfare agents. However, a universal methodology for detection and prevention of CBE materials in the use of these devices has proven difficult. Herein, we discuss our efforts towards the development of a modular, robust, inexpensive, pervasive, archival, and compact platform (android based smart phone) enabling the rapid detection of these materials.

Keywords: Smartphone, ubiquitous sensing, explosives sensing, chemical sensing, biological sensing

1. INTRODUCTION

While the literature abounds with examples of technologies that enable chemical, biological, and explosives (CBE) threat sensing,[1-7] there exists a need for development of modular and robust systems for rapid, handheld detection of CBE. Ideally, a CBE sensing device should be easy to use, be adept at monitoring a variety of analytes, provide consistent performance regardless of atmospheric conditions, and have the capability of uploading information (material information, GPS coordinates, images, time, date, etc.) to a dedicated network. The onboard functionality of smartphones coupled with the necessity to remove the human factor from analysis of test results, especially from more subjective tests such as colorimetric assays, is driving research momentum towards the utilization of smartphone technology. The ubiquitous availability of smartphones and parallel advances in on-chip diagnostics, microfludics, and smartphone platform technologies have enabled state-of-the-art smartphone sensing devices.[8] Similarly, there have been a number of recent reviews discussing technologies that incorporate many of these characteristics into "ideal" devices for a variety of uses including hazardous materials sensing and point of care diagnostics (POC).[9-14]

Smartphone enabled CBE detection has the potential to provide immediate results to mobile personnel (border patrol, ATF agents, law enforcement, military, etc.) allowing rapid and appropriate response in real-time to emerging threats. Additionally, these handheld gadgets have the potential to revolutionize the industry and save immense amounts of time and resources by removing the need to collect, preserve, and ship samples to a secondary facility for testing and archiving. Figure 1 illustrates the components that are necessary for fully integrated CBE and POC detection devices, and the linchpin in the broad based adoption of this technology is the smartphone. We are currently working on the production of a handheld, field-portable device with archival capabilities for ubiquitous sensing applications, including CBE detection. Specifically, the focus of this paper is to highlight recent work in coupling commercial off the shelf (COTS) explosives sensing kits, a novel smartphone adapter, and a graphical user interface (GUI) that will mobilize CBE sensing applications.

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Figure 1: Diagram outlining example types of materials (Chemical Hazards, Explosive Chemicals, and Biological Chemicals) that would be integrated into a modular sensing platform.

2. EXPERIMENTAL

2.1 Materials

The energetic samples trinitrotoluene (TNT), dinitrotoluene (DNT), and 2,4,6-Trinitrophenylmethylnitramine (Tetryl) were obtained from Cerilliant Analytical Reference Standards, a Sigma-Aldrich company (10 mg/mL, 99.9% purity). All aqueous solutions were prepared with nanopure water (ddH_2O). All chemicals and supplies were purchased from Fisher Scientific or Sigma-Aldrich and were the highest grade and purity available. All serial dilutions were prepared from stock energetic samples diluted with acetonitrile, water, or ethanol.

2.2 Methods

Explosives Detection – Colorimetric test kits were purchased commercially from their respective manufacturers [IDEX and E.L.I.T.E. EL100 (Field Forensics), MIPS Raptor Wipes (Raptor Detection, Inc.), Drop-EX Plus (Mistral Security)] and used according to manufacturer specifications.

Smartphone Adapter – A Stratasys FDM Titan Model and standard materials and techniques were used for 3D printing of the adapter housing. The adapter was designed to mount directly onto any smartphone protective cover and is independent of phone and cover design revisions.

3. RESULTS AND DISCUSSION

3.1 Target and Platform Selection

More than 17 different colorimetric kits for explosives and homemade explosives (HME) precursors are currently being tested in theater applications. We tested a number of different COTS kits to compare the ease of use, limit of detection (LOD), reproducibility of results, and portability. The IDEX (Field Forensics) was selected for further development due to rugged design, reproducible results, few false positives, low LOD, and small footprint. This kit was also very easy to use and did not require any additional materials or heater unit. Figure 4(A) and Figure 4(B) illustrate the size of the IDEX unit. In Figures 4(C) and 4(D) the active area of a reacted IDEX unit is shown after exposure to varying concentrations of TNT. A number of different nitroaromatic explosives (TNT, DNT, Tetryl) were tested to determine the varying degree of color change and LOD (data not shown).

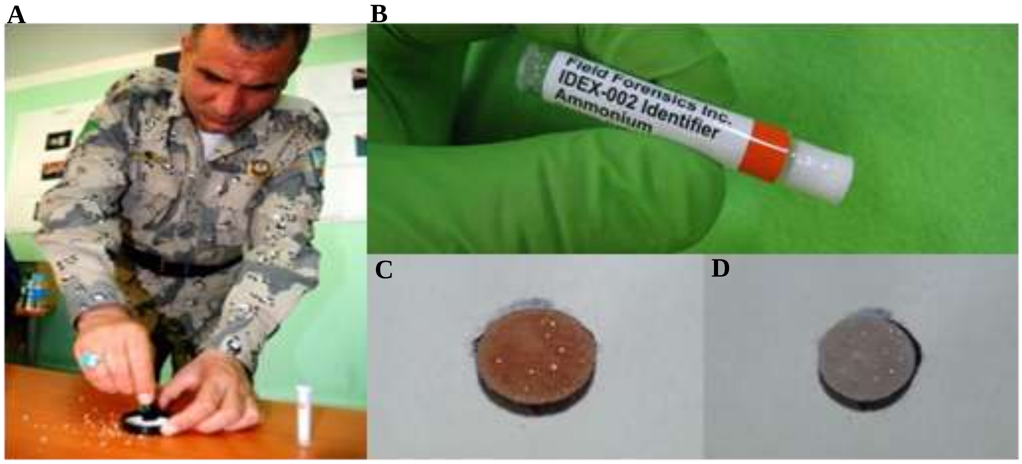

Figure 2: IDEX Series Explosives and Precursor Identifiers (A) IDEX test kit training at Afghan Border Police Headquarters in Kabul[21] (B) Unreacted tester unit (C) Test strip after exposure to 400 μg/mL TNT (D) Test strip after exposure to 3.2 μg/mL TNT.

3.2 Smartphone Technology

Smartphone technology has rapidly increased in sophistication with the integration of a wide variety of features such as multiple communications mediums, increased memory capacity, power reduction, global positioning systems (GPS), audio recording, accelerometers, increased video and picture resolutions, and greater multiprocessing speeds. Such advances make smart phone technology a ripe platform for the development of sophisticated miniature mobile sensors with real-time signal processing capability. Recently, the National Security Agency (NSA) has modified the Android platform to provide highly secure cellular communications for military applications.[22] In addition, the open source Android mobile operating system further makes research and development on smart phones a viable solution for mobile sensor platforms.[23] In contrast, the iPhone is a more guarded platform that does not allow developer access to the operating system source code for modification.[24] For our development we have chosen the Samsung Galaxy S3 (Figure 3) running Android with a 1.4GHZ Quad core ARM processor, 1GB internal RAM, external memory expansion up to 64GB, and an 8 MP JPEG camera.

Figure 3: Samsung Galaxy S3 smartphone selected for chemical, biological, and explosives sensor integration.

3.3 Adapter Description

Upon selection of the IDEX kit for further development, the adapter was developed specifically to house these kits. It is important to note that while this research specifically focused on this individual kit, any colorimetric assay can be quantified by the software package developed. A number of considerations were taken into place when developing the adapter. The mechanical requirements included: Small, robust, repeatable, uniform test cartridge placement, and compatibility across multiple phone revisions. The latter was one of the key factors in order to ensure that the adapter developed would not be rendered obsolete by revisions in phone design. Figure 4A illustrates a computer aided drafting (CAD) drawing of the adapter unit. The adapter was created using a Stratasys FDM Titan 3D printer. The following design implementations were used to address the mechanical requirements including: mirror to bend optical axis, compact battery and electronics, snap-in cartridge holder, repeatable cartridge depth-stop, singe LED alignment, and direct attachment to carrying case thereby reducing phone revision incompatibility. Figure 4B illustrates the first version of the 3D printed housing coupled to the case and smartphone, respectively.

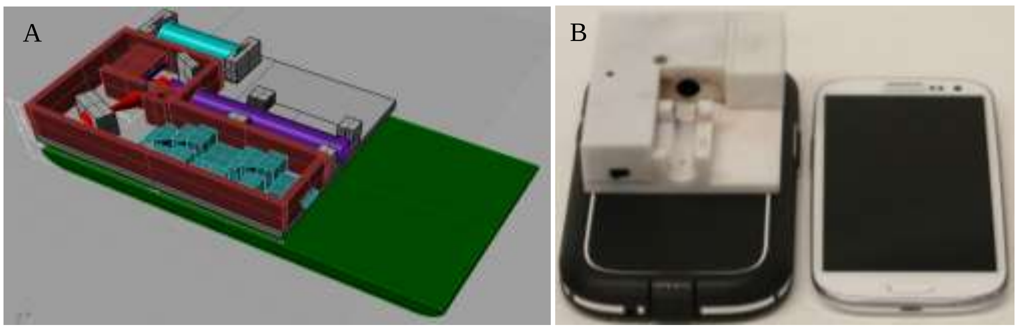

Figure 4: Adaptor Images (A) CAD diagram of adapter to house test strips (B) Image of 3D printed adapter directly mounted to smartphone case.

3.4 Detection System

In many cases the user of a biochemical assay detection system can easily observe the color response of an assay and make an accurate decision on the detection of the presence of a target chemical or substance. In other cases it may be difficult to make such a decision because of subtle color changes not easily detectable with the human eye. To aid the user, an automated field deployable biochemical detector has been designed and implemented using smart phone technology to augment this decision making process. The detection unit is a binary detector that indicates the presence or non-presence of the chemical target of interest. The operating procedure of the detector is to first perform training or calibration. Once performed, the user may place an assay into the custom fixture making certain that the LED light is illuminating the assay sensor, and then through an Android application initiate the detection unit to acquire a photo of the assay sensor and execute the digital signal processing (DSP) algorithm on the image. Once the algorithm completes, the user will be presented with a status indicating the presence or non-presence of the particular chemical on the assay.

3.5 Detection Algorithm

The detection algorithm is purely written in Java, the programming language for the Android platform. In addition the algorithm makes use of Apache Commons Math which is a library of lightweight, self-contained mathematics and statistics components (Foundation, 2013). The algorithm is based on the well known Mahalanobis distance calculation. Fundamentally the algorithm detects the distance of RGB color shifts away from a known RGB calibration reference color. The JPG image acquired by the phone's camera uses the maximum camera resolution of 3264 by 2176 pixels. An example of a typical image is shown in Figure 5A. The circular assay swath uses approximately ¼ of the image which is approximately 1,775,616 pixels. Of these, training and detection processing is done on an arbitrarily selected subset size of 71,539 pixels which are shown in green in Figure 5B. The reference color is trained on this subset of pixels from an assay color swab with no chemical applied. Finally, when running forensic tests in which a chemical is present on the assay, any detected color shift falling a Mahalanobis distance away from the reference and above a preset threshold is reported as an affirmative detection. The acquisition of the image and the processing takes approximately two seconds on the Galaxy S3.

3.6 Graphical User Interface (GUI)

A prototype GUI was developed in Java which is the native language for the Android platform. The GUI has been developed as an engineering interface to allow for easy insertion and test of various algorithms for performance characterization. It is expected that a final end user GUI will differ significantly from this engineering GUI.

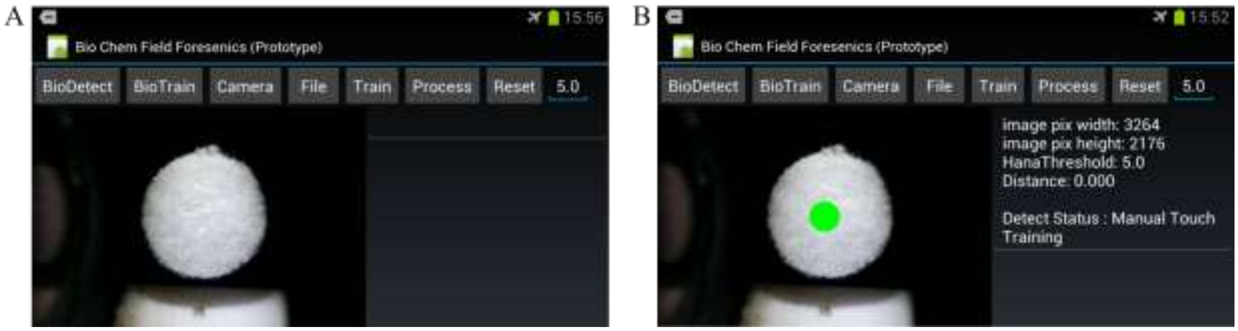

Figure 5: Screen capture of GUI. (A) Image of IDEX test strip in camera field of view. (B) IDEX test strip after manual touch training on the image.

The various GUI buttons BioDetect, BioTrain, Camera, File, Train, Process, Reset, and Threshold settings work collectively to acquire, test, and characterize performance. Figure 5A and 5B show the prototype interface. Figure 5A shows an image of an IDEX test kit inserted into the test fixture with the LED light turned on. Figure 5B shows a photo of the result after the user clicks on the BioTrain button to train the algorithm on a reference sample. The green dot is displayed on the test image indicating the training pixels used in the detection algorithm (approximately 30k pixels are used).

The following gives a more detailed description of the GUI interface. The two primary control buttons are *BioDetect* & *BioTrain*. After clicking the two buttons, a green dot is displayed on top of the image indicating the pixels used in the detection algorithm (approximately 30k pixels are used). All other buttons are for finer control over the application, and can be useful for gaining a better understanding the algorithm’s performance. The following descriptions are written as would be provided in a user manual or user instructions for the GUI interface.

BioDetect - Clicking this button will take a photo of the actual chemical test stick and have the software automatically process the image. The result will be a binomial detection status. A status of *Affirmative* or *Negative* will be reported to indicate a detection or non detection. The user will not be given control of camera settings when clicking this button.

BioTrain **-** This button is for calibration, which should be done before use. Once calibration is complete, it generally is not required again. Place an unused forensics stick in the carrier, and click this button. A camera view of the stick will be shown. Be certain the light on the lens fixture is turned on. Tap the image and a picture will be taken and stored on the camera’s SD memory card. Statistics will be computed and stored in the applications internal memory. A status message will be displayed indicating the training is complete. The previous training will be deleted.

Camera **-** Clicking this button will bring up the native camera application to take a picture. This allows the user to have more control over the camera when taking the picture, and is mainly intended for developmental purposes.

File **-** Clicking this button will allow selection of a specific image file stored on the camera. The file can be used to either *Train* or to *Process*.

Train **–** This is a legacy function that was used in the development of the initial GUI, but will likely be removed from further revisions**.** Clicking on *Train* will cause the software to train on the currently viewed image. This is useful for development, as well as working with different calibration files. Upon clicking *Train*, all default detection statistics will be computed from the currently viewed file and stored and used for further detection processing. The previous training will be deleted.

Process **–** Clicking process will cause the presently viewed image to be processed with the detection algorithm. It allows you to first select a file with the *File* button, and then to click on this *Process* button to do detection processing.

Number in the Right Hand Corner - There is a number in the right hand corner next to the *Reset* button. This is a threshold value set for the Manalanobis detector. The default value was set experimentally through trials with a number of various images. When the detection algorithm executes from clicking the BioDetect or Process buttons, processed values at or above this number are considered detections.

Reset – The reset button resets the screen, but does not affect the state of algorithm.

3.7 Calibration and Testing of Smartphone GUI for Explosives Sensing

Initial testing with the COTS explosives kits are promising and suggest that a COTS kit coupled with the smartphone GUI not only provides a fast and archival readout, but also reliable data. However, further testing to include LOD and receiver operating characteristic (ROC) curve determinations is ongoing and necessary. Future studies include side by side and standalone comparison of complementary explosives in more complex matrices.

4. CONCLUSION

The ability to rapidly detect CBE materials with reliable, rapid, robust technologies is critical to addressing the persistent threat to U.S. troops in the current war on terror. This work highlights our progress towards development of a universal, hand-held, and modular methodology for detection of CBE materials. While still in the preliminary stages, the recent advances illustrate the move toward the rapid detection and identification of the precursor materials used in development of improvised explosive devices, homemade explosives, and bio-warfare agents.

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